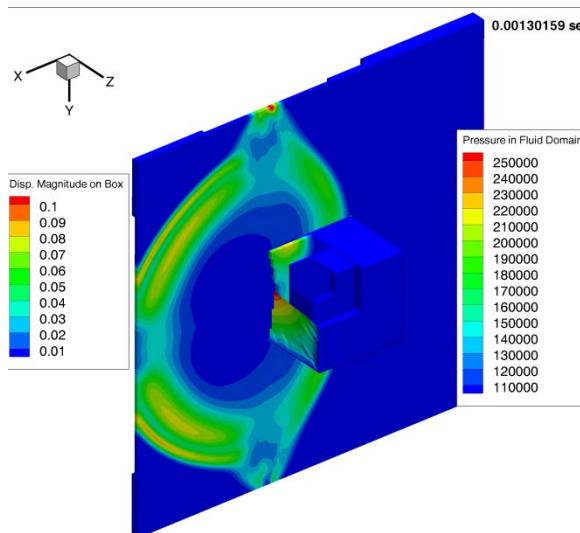


# Physics-Based Simulations of Fluid/Structure/Dynamics Interactions in Scenarios Associated with Blast



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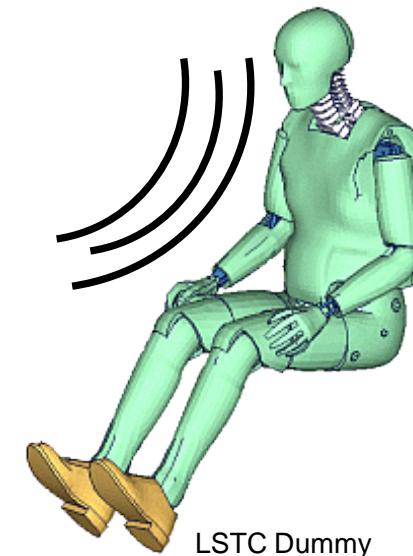
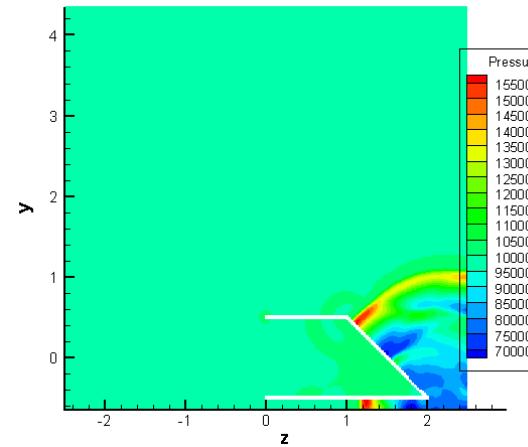
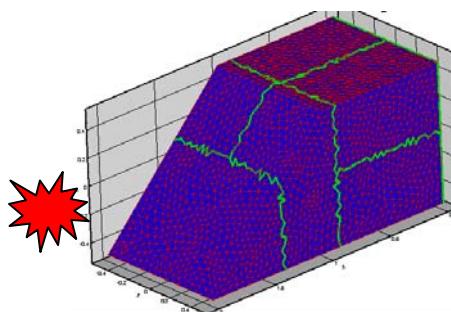
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# Objectives

- ❑ Develop vehicle occupant blast load simulation
  - Fast and accurate - Physics and HPC
  - Cost efficient – Open source code
  - Flexible and User-friendly



# Outlines

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- Background
- Technical Approach
- Results and Discussion
- Summary



# IED and TBI

## ***Improvised Explosive Device (IED)***

- Over 60% of the blast injury in OEF and OIF in 2009
- Penetration and direct injuries
- Remains weapon of choice and major threats
- Survival rate increased with armor (head, body)

## ***Blast Traumatic Brain Injury (TBI)***

- “Signature” injury in OEF and OIF
- Primary blast injury caused by blast induced pressure change
- Battle field and in-theater innovations in treatment lowered killed:wounded ratio
- Simulation to further enhance vehicle occupant survivability



# Fundamental Physics and Simulation

## ***Gas Dynamics - CFD***

- Spatial (three-dimensional) and temporal (time accurate)
- High pressure ratio wave of small time scale
- Pressure wave numerical resolution in 3D
- Moving/deforming immersed boundary
- Computationally intensive

## ***Computational Structural Dynamics - CSD***

- Spatial (three dimensional) and temporal (time-accurate)
- Materials dynamic behavior
- Large deformation or fragmentation
- Computationally intensive

## ***Motion Dynamics – 6DOF***

- Kinematics and dynamics of body motion
- Six degree of freedom (6DOF) motion equations

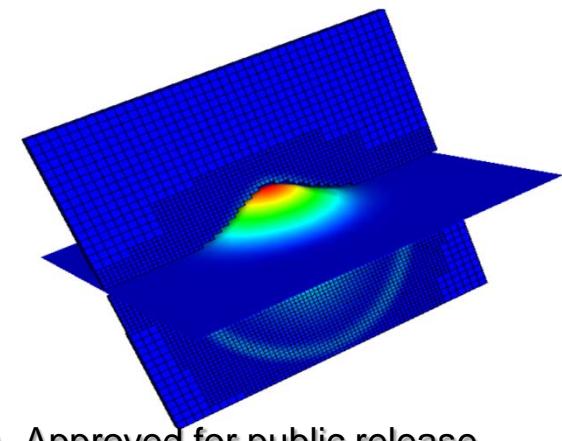
Computationally intensive



# Simulation Platform (1)

## ***Fluid Dynamics and Structural Dynamics*** ***Virtual Test Facility (VTF) from Cal Tech***

- Developed at Cal Tech's Center for Simulation of Dynamic Response of Materials.
- 3D dynamic response of materials subjected to strong shocks and detonation waves propagate in fluids
- Explicitly coupled Eulerian-Langrangian simulations
- Adaptive mesh refinement for Cartesian finite volume fluid solver
- High order sub-division FE thin-shell structure solves
- Fracture and fragmentation
- Highly parallelized CFD and CSD solvers
- Open-source



# Simulation Platform (2)

## *Rigid Body Motion Dynamics*

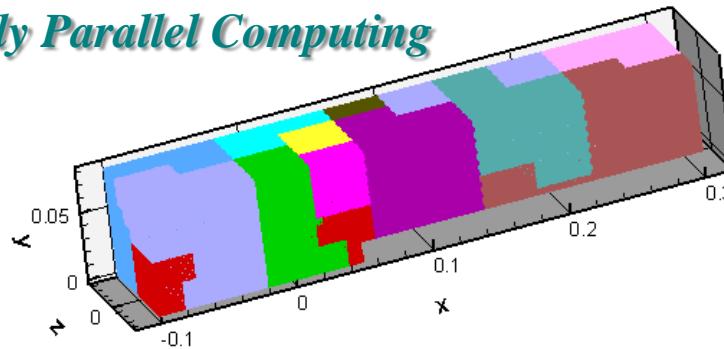
### *WMU Enhanced Solver*

- Geometry flexibility
- Directly coupled to VTF with multiple bodies
- Open-source

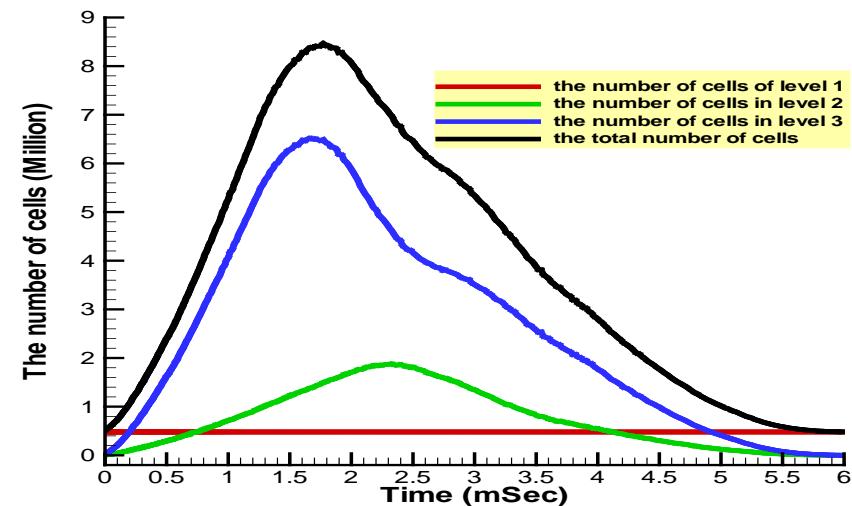
## *Coupled Fluid/Structure/Dynamics Solver*

- Vehicle Occupants Blast Load
- High Performance
- Low Cost

## *Massively Parallel Computing*

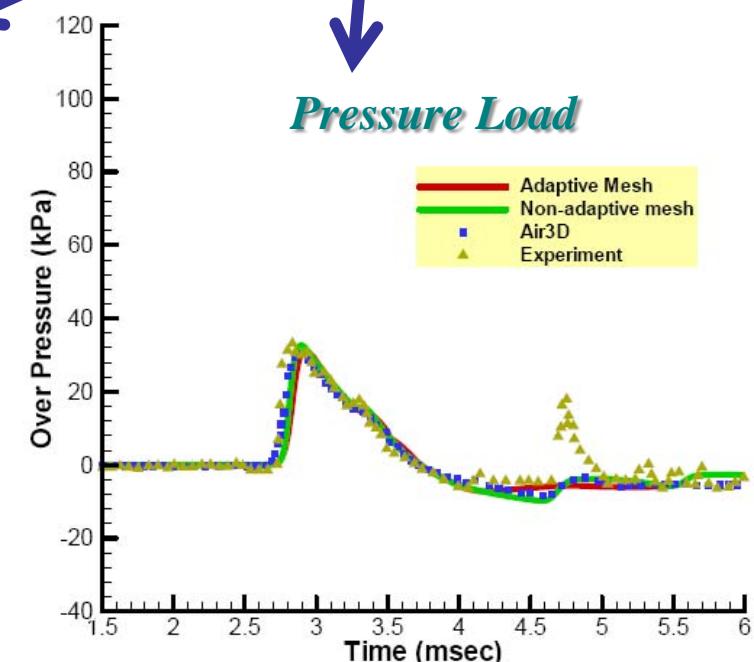
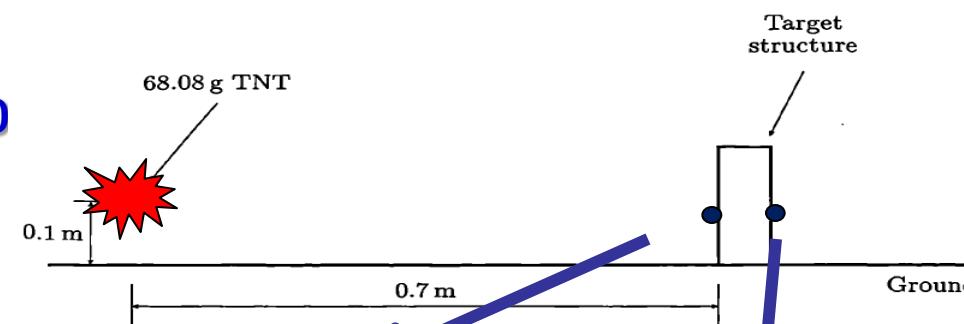
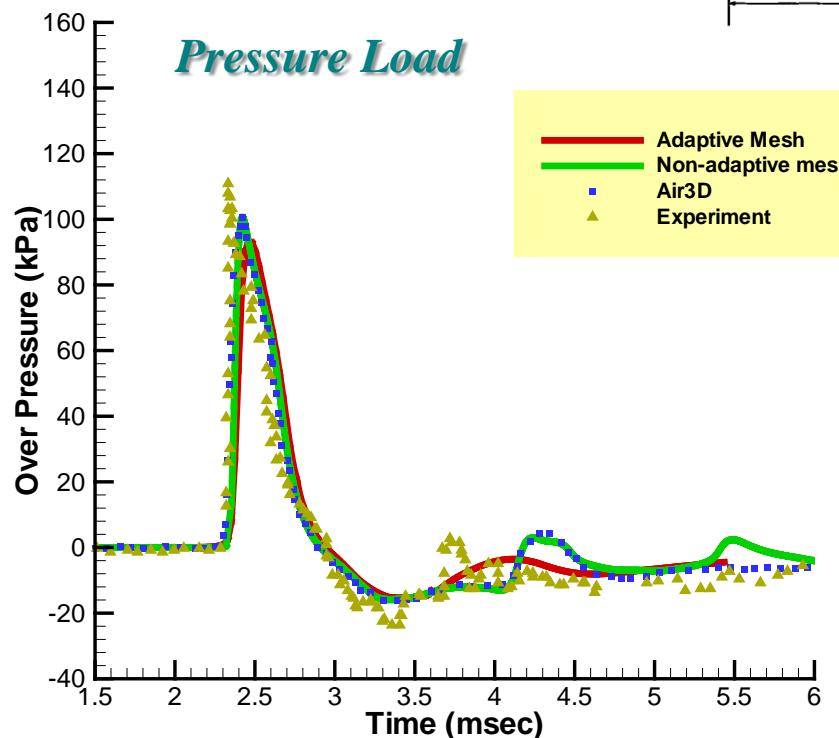


## *Adaptive Mesh Refinement*

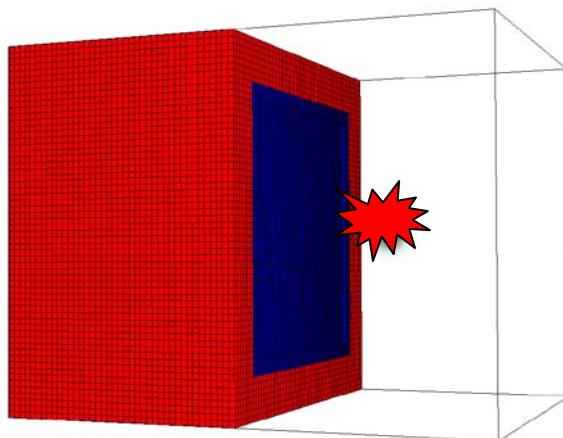


# Free Air Blast Wave Propagation

- $P_{TNT} = 2.89 \text{ GPa}$
- Base Mesh:  $200 \times 150 \times 50$
- Two Pressure Loads

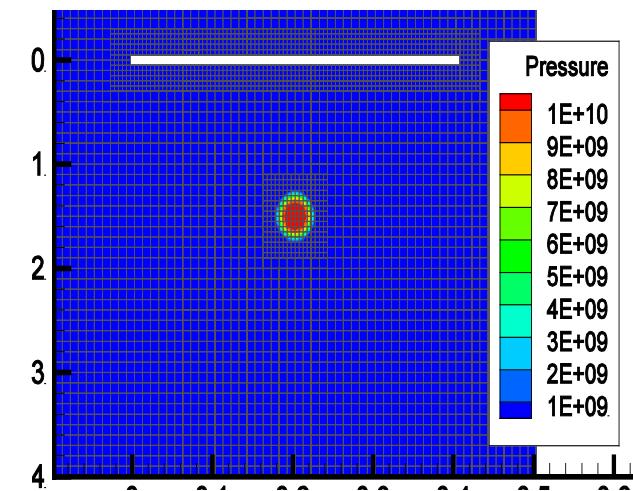


# Metal Plate in TNT Blast (1)

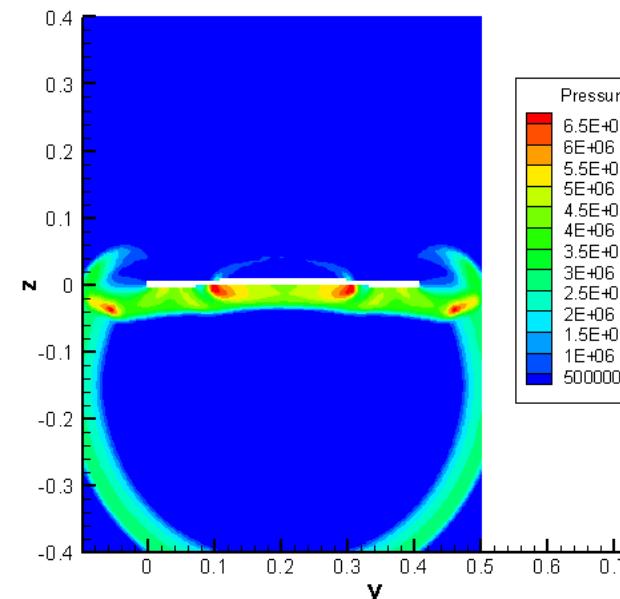


- 150 g C4
- Two standoff distances
- AL6XN SS plate thickness 1.9 mm
- 8 Compute Node

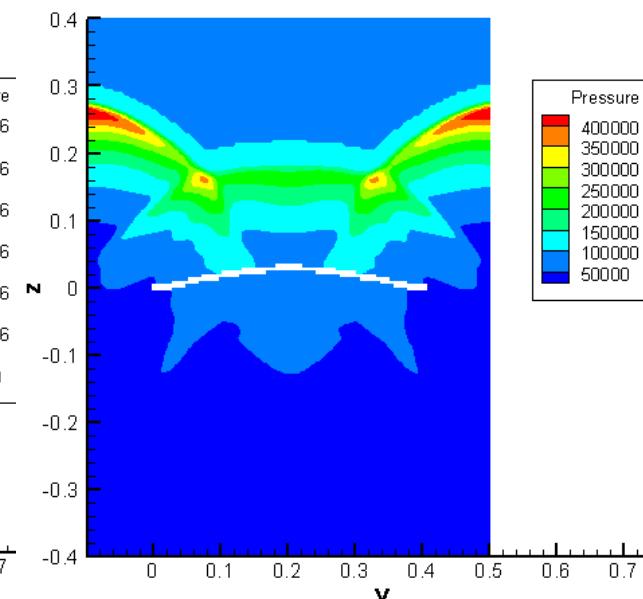
*Pressure Contours at  $T_0$*



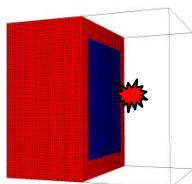
*$T_0 +$*



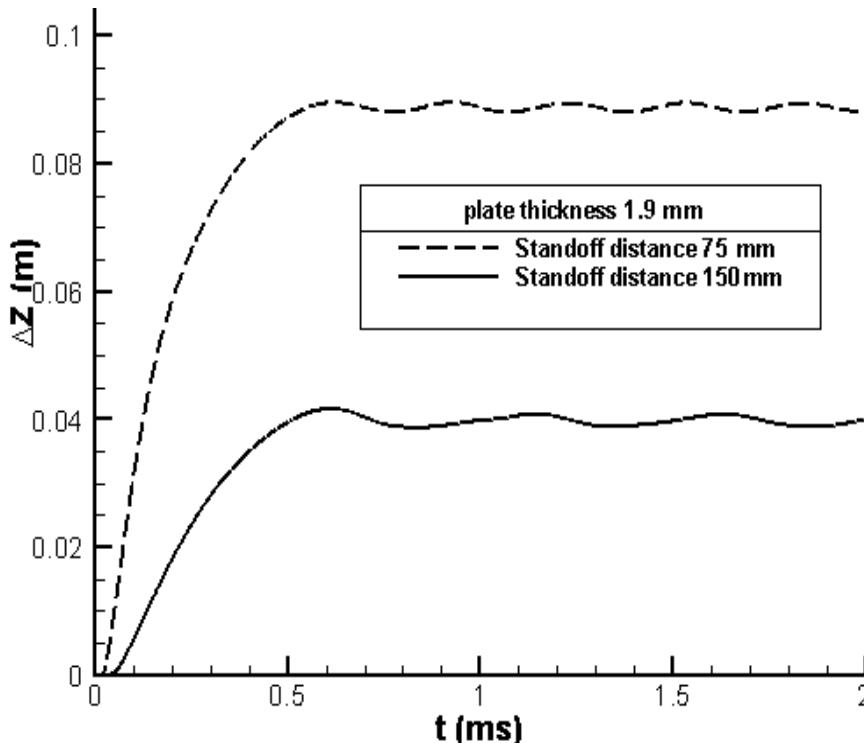
*$T_0 ++$*



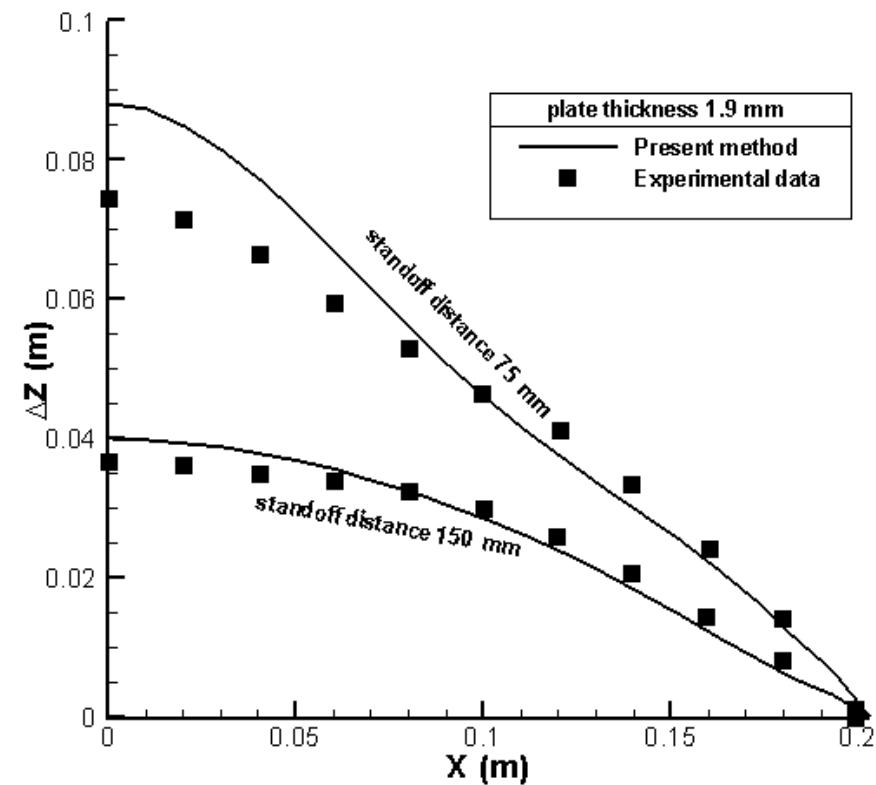
# Metal Plate in TNT Blast (2)



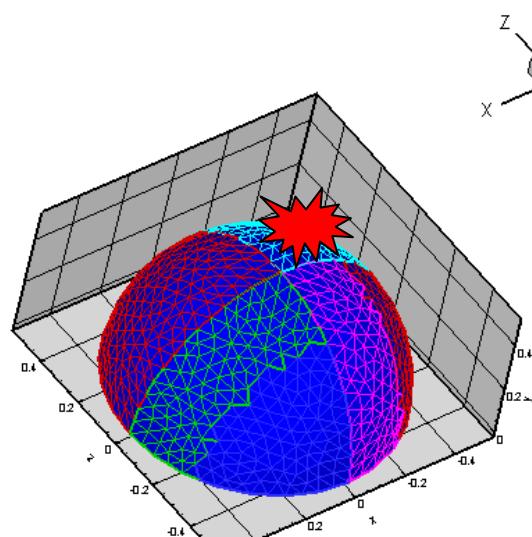
SS Plate Centerpoint  
Deformation History



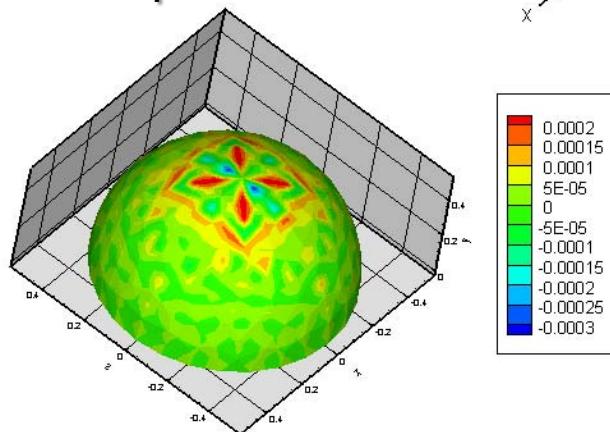
SS Plate Deformation  
Contours



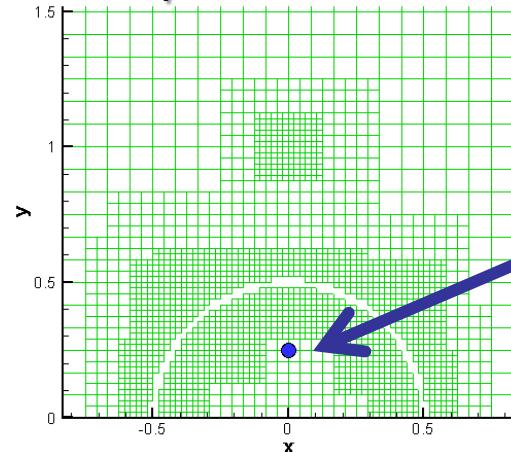
# Blast Over Hemisphere Dome (1)



Rooftop Pressure Load

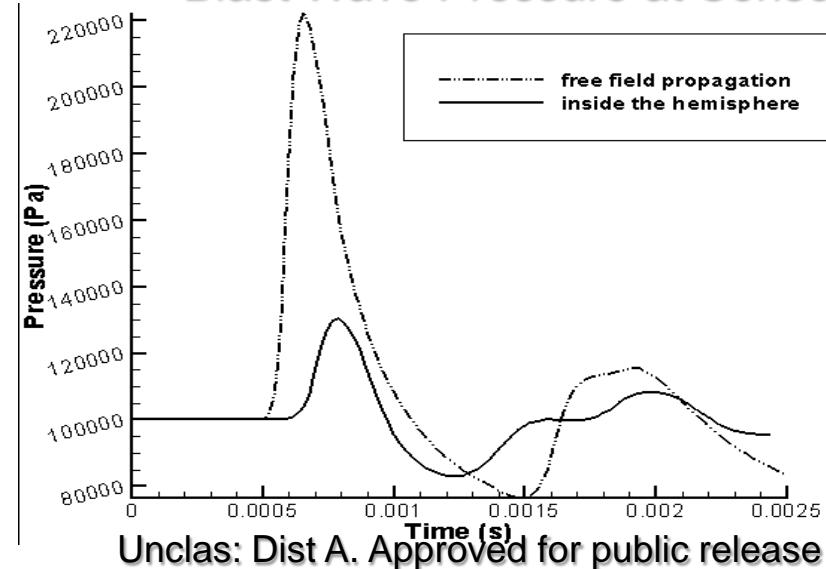


Adaptive CFD Mesh

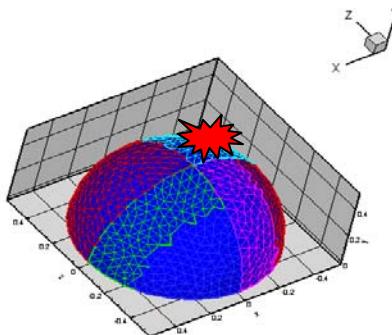


pressure sensor

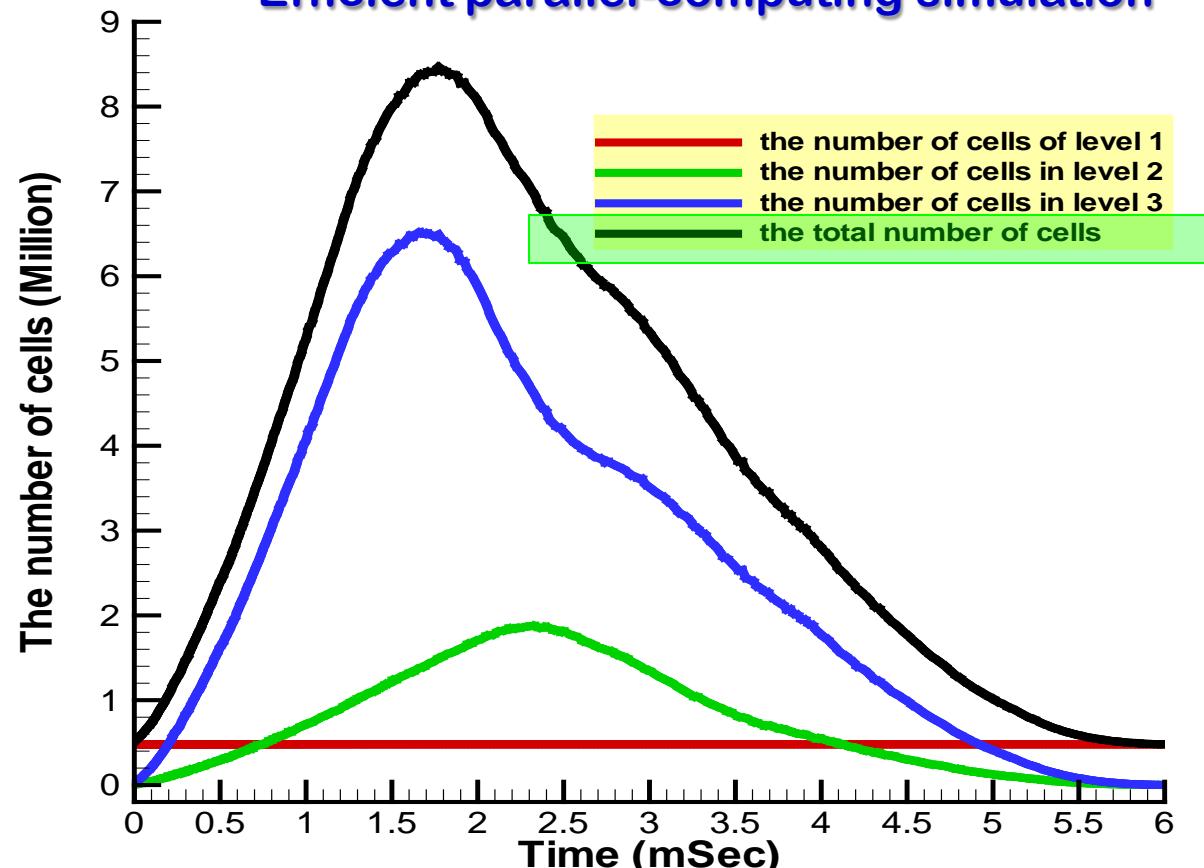
Blast Wave Pressure at Sensor



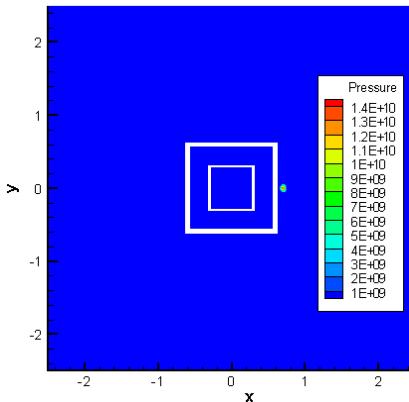
# Blast Over Hemisphere Dome (2)



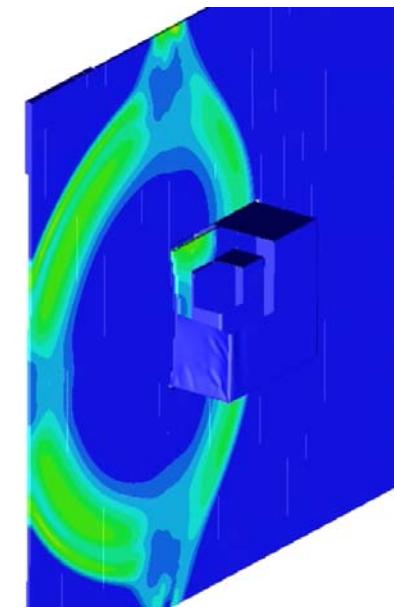
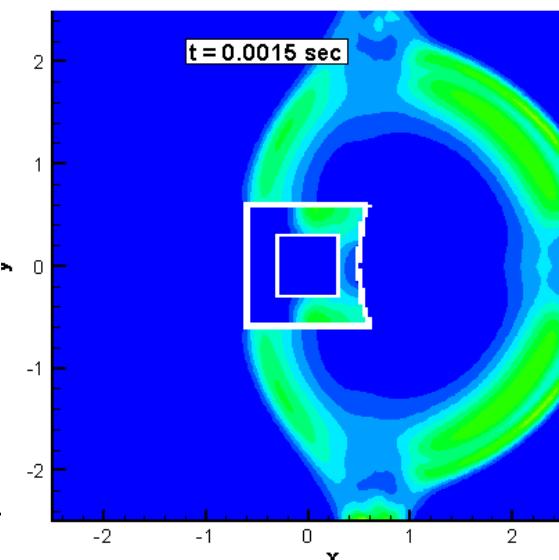
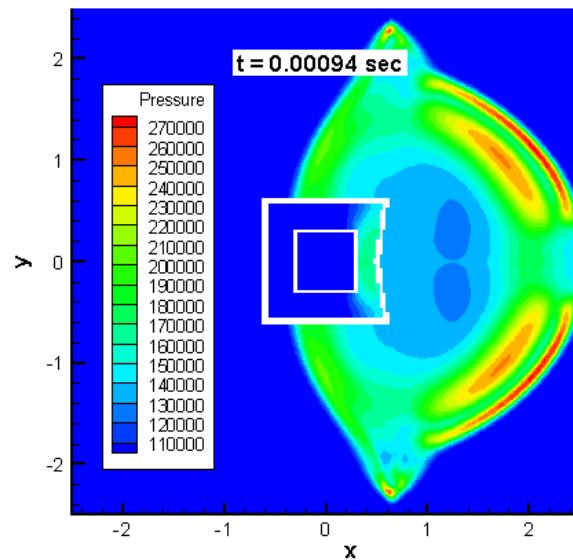
- 3 Level of adaptive mesh refinement
- Total # of cell adapt to accuracy need
- Efficient parallel-computing simulation



# Blast off Boxes (1)



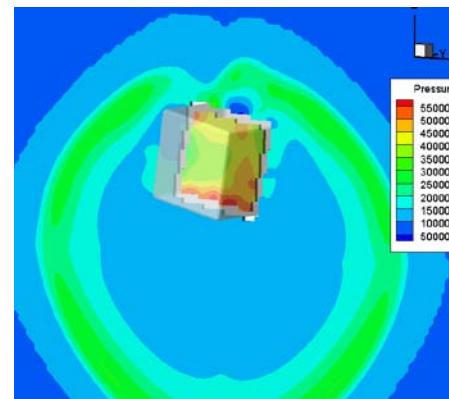
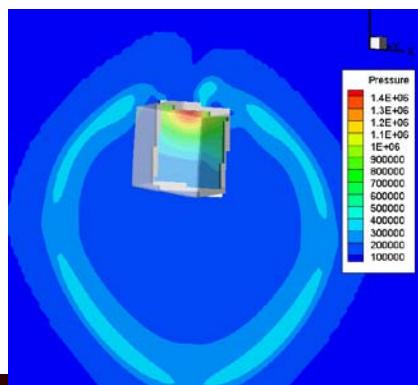
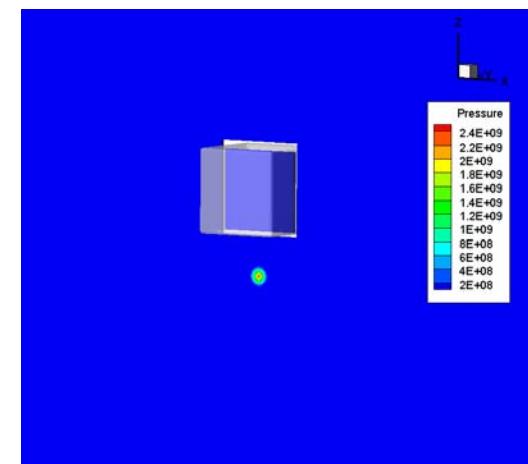
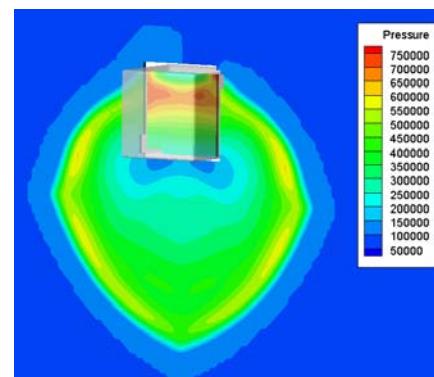
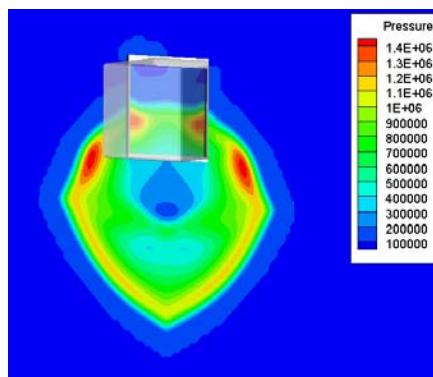
- Two boxes with one centrally located inside the second
- The outer box deforms elastically; the inner box rigid and fixed in space



Pressure Contours & Box Deformation

# Blast off Boxes (2)

- Blast initiated under a single rigid box
- Unconstrained body motion by 6-DOF



Body 6-DOF Motion & Pressure Contours

# Concluding Remarks

- ❑ Developed physics-based computer simulations of the effects of fluid-structure interactions due to blast
  - ❑ Open-source software offers accurate and fast simulations
  - ❑ CFD in multiply connected domain
  - ❑ Generic geometries
- ❑ Developed fluid-structure-dynamics interactions mutiphysics solver
  - ❑ Vehicle occupant motion and deformation due to direct/indirect exposure to blast wave
- ❑ In the future,
  - ❑ Apply to realistic dummy model
  - ❑ Develop and couple multi-body dynamics capability for human-like dummy model
  - ❑ Deliver software for time-accurate vehicle occupant blast wave load simulations to TARDEC

